GEOPHYSICAL SURVEY
GROUND WATER EVALUATION
KAUPULEHU PROJECT
KULOLO QUADRANGLE
ISLAND OF HAWAII

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ISLAND OF HAWAII

Prepared For:

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(Our Project #90020)

Table of Contents

1.0 INTRODUCTION

This report contains the results of a geophysical survey to assist the evaluation of fresh water resources near Puu Nahaha, Kulolo Quadrangle, on the Island of Hawaii. The work was performed by Blackhawk Geosciences, Inc. (BGI) for Potomac Investment Associates (PIA) on the Kaupulehu Project on April 1 through 4, 1990.

The objectives for the geophysical survey can be understood from the hydrogeologic cross-section, typical of a volcanic island, shown in Figure 1-1. The volcanic rocks are generally highly permeable and rainfall rapidly infiltrates into the ground and migrates downward to the water table, and eventually discharges into the ocean. Fresh water in these settings is found in two environments.

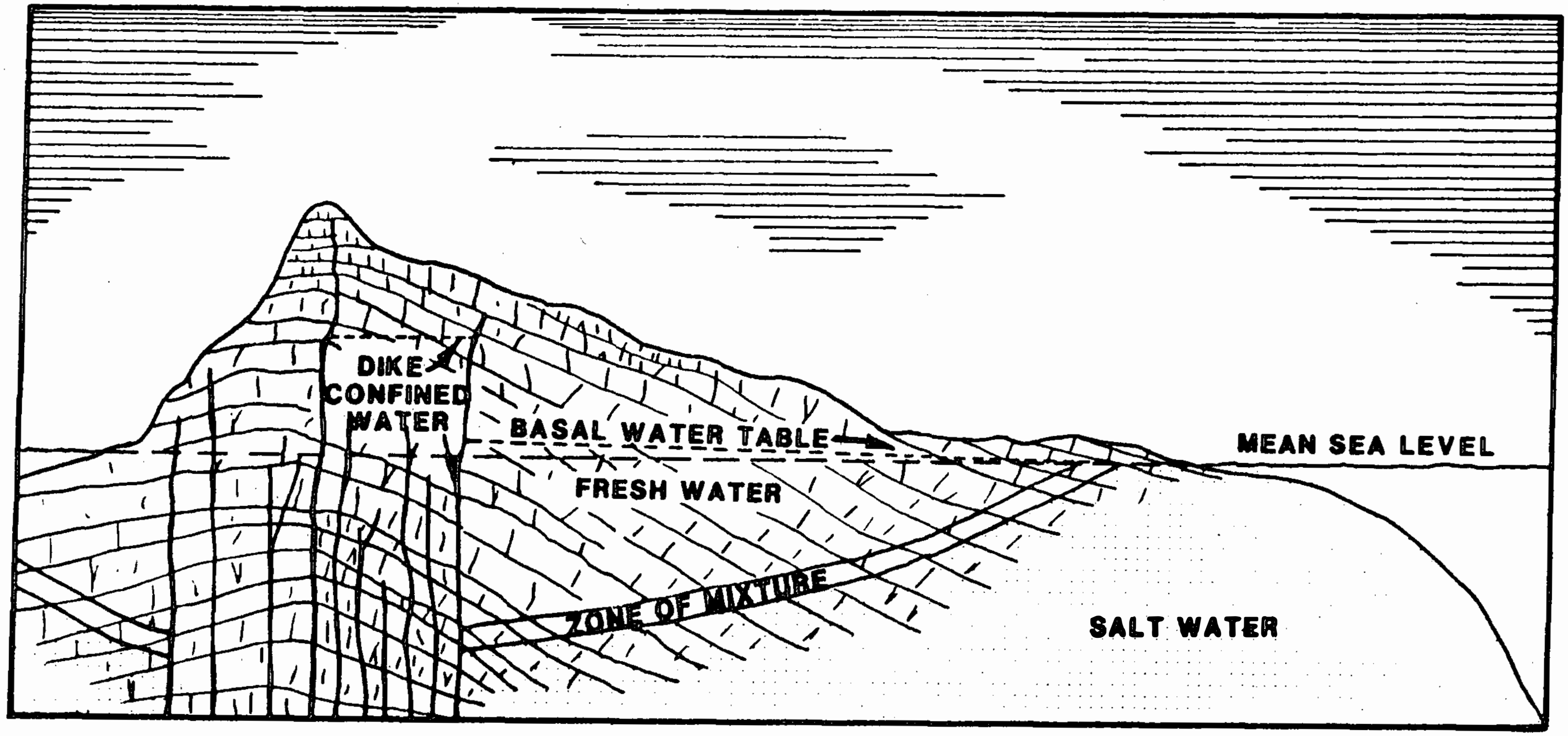
1. <u>Dike confined waters</u>. Above the rift zone intrusive dikes originating from a magma source below can form ground water dams, and behind these natural dams significant quantities of ground water can be stored.

2. <u>Basal fresh water</u>. The high permeability of the volcanic rocks allows sea water to enter freely under the island, and a delicate balance is reached where a lens of fresh water floats on sea water. The Ghyben-Herzberg relation states that for every foot of fresh water head above sea level there will be 40 ft of fresh water below sea level.

The basal water resource was the focus in the investigations for PIA. The drilling depth to the basal fresh water lens rapidly increases with elevation, and the objective of geophysical surveys is to determine the drilling depth to fresh water and the thickness of the fresh water lens. The impetus for using geophysics is that the cost of a geophysical station is about one-five-hundredth of the cost of drilling a well at elevations above 1,000 ft. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths.

The geophysical method employed was time domain electromagnetic (TDEM) soundings. This method was selected because it has proven effective in prior surveys in similar settings in Hawaii.

The specific objectives of the geophysical survey on the Kaupulehu Project were to expand the evaluation of the proposed well locations for the Four Seasons Resort Development.



BLACKHAWK GEOSCIENCES, INC.

SCHEMATIC HYDRO-GEOLOGIC
CROSS SECTION
Potomac Investment Associates
Kaupuleha Project

PROJECT NO.: 90020 FIGURE 1-1

2.0 LOGISTICS AND DATA ACQUISITION

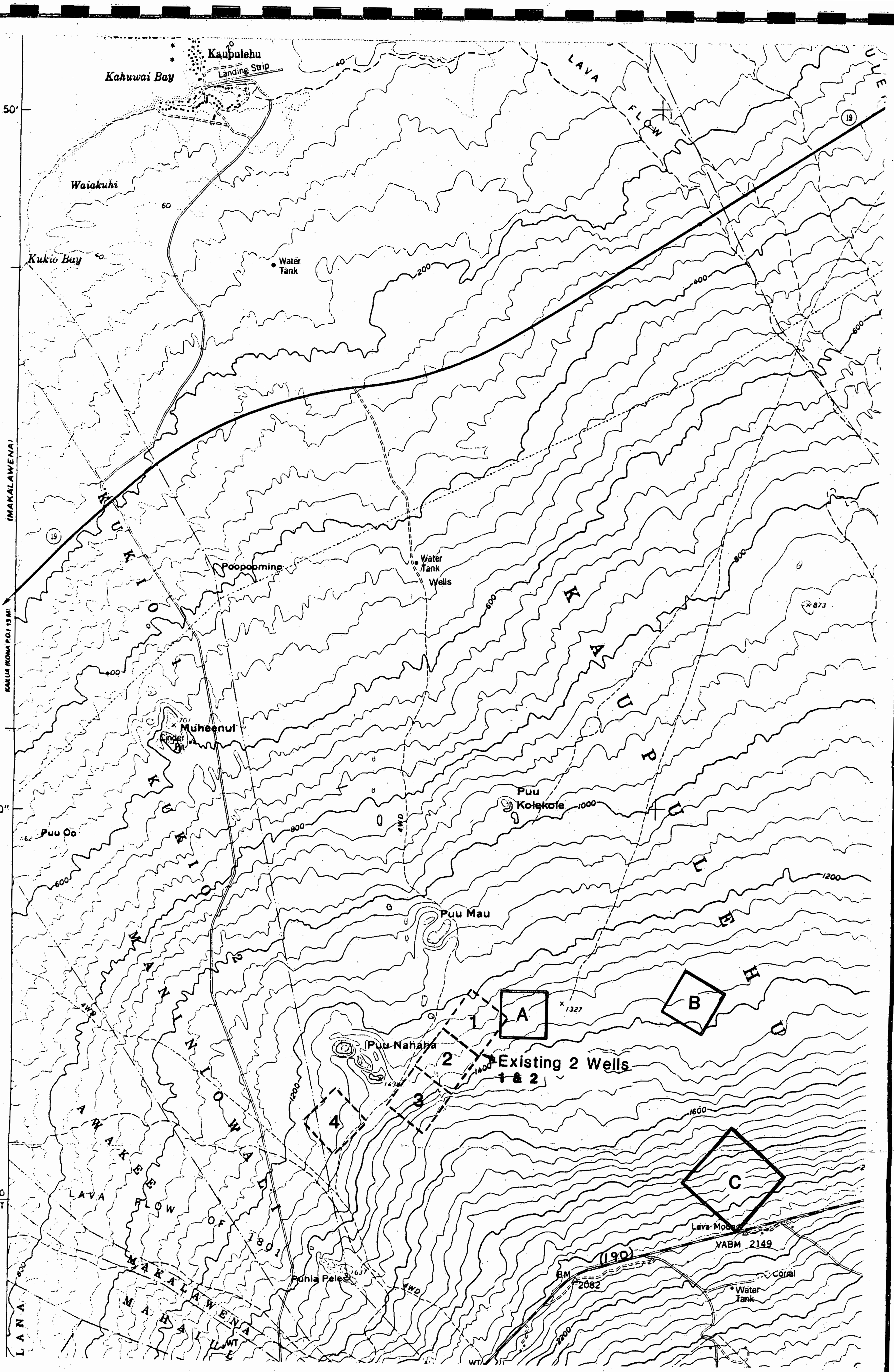
A brief description of the fundamentals of TDEM is given in Appendix A. Briefly, the logistics of a TDEM measurement consist of:

1. Laying out a square loop of insulated wire. A generator placed in the loop is used to drive current pulses through this closed loop. The dimensions of the square loops employed depend on the exploration depth requirements. The dimensions of the loops used for PIA were 1,000 ft by 1,000 ft on each side for loops A and B, and 1,500 ft by 1,500 ft for loop C.

   Transmitter loop wires were positioned with one wire corner near Route 190 for loop C. Loops A and B were positioned with the aid of a helicopter supplied by PIA and Papillon Helicopters. Access to these sites on foot was not cost-effective.

2. Making a measurement with a receiver in the center of the loop. The data acquired at each station was stored in the field on a solid state data logger and subsequently dumped to a computer at the end of each field day. The data acquired at each station usually consisted of measurements at several receiver gain settings and transmitter frequencies in order to assure data quality and to obtain data over the largest time range possible. Data quality was generally very good.

During the 2 days (more than 20 hours total) of field work 3 stations (soundings) were completed. This time included reconnaissance to determine access to sites A & B. A daily log of field activity is given in Table 2-1. Figure 2-1 shows the location of the soundings conducted for PIA. The position of soundings A and B were positioned approximately where requested by Tom Nance, water resources consultant.



Potomac Survey

Kajima Survey

1000 0 1000 2000 3000 4000

SCALE - FEET

BLACKHAWK GEOSCIENCES, INC.

TIME DOMAIN EM SURVEY
LOCATION MAP

Potomac Investment Associates
Kaupuleha Project

PROJECT NO.: 90020

FIGURE 2-1

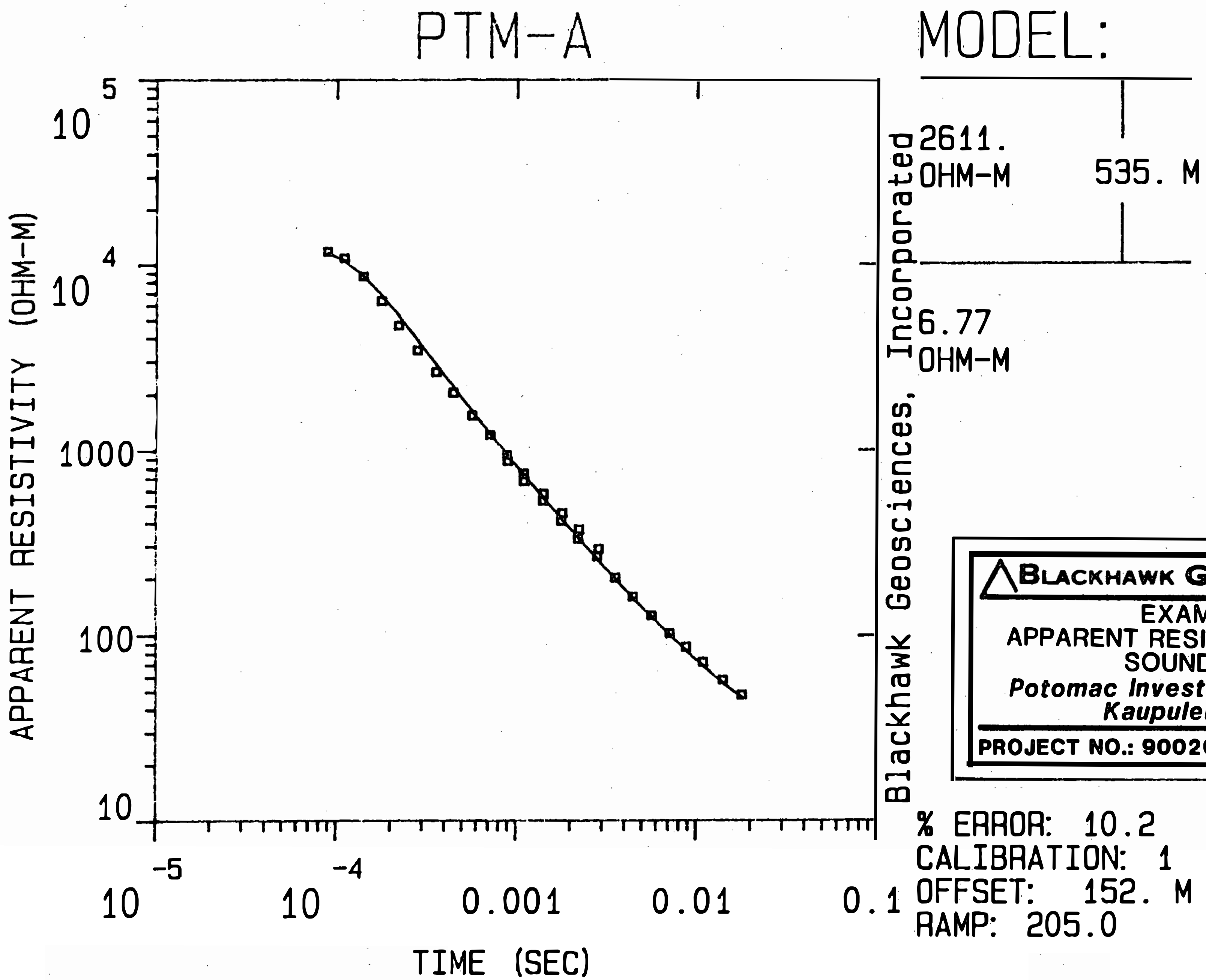
Table 2-1. Daily log of field activities

Date (1990)	Activity
March 26	Mobilize to Kailua-Kona, HI
March 27-31	Other surveys being conducted.
April 1	Site reconnaissance.
April 2	Other surveys being conducted.
April 3	Measurement sounding C.
April 4	Measurement of soundings A and B.
April 5-10	Other surveys being conducted.
April 11-13	Pack and store equipment and demobilize from Kailua-Kona, HI to Golden, CO.

3.0 DATA PROCESSING

The objective of data processing is to derive from the TDEM measurements in the center of the loop the resistivity layering in the earth. The procedures of data processing are discussed in Appendix A. The results from data processing for each station are contained in Appendix B. An example data set is given in Figures 3-1 and 3-2 for station A adjacent to loop 1 from the Kajima Engineering and Construction, Inc. (KECI) survey. Figure 3-1 shows the measured data points (in terms of apparent resistivity) superimposed on a solid line. The solid line represents the computed behavior of the true resistivity layering shown on the right. Figure 3-2 lists in column 4 the error between measured and computed data in each time gate.

Figure 3-1 shows that the resistivity layering in the upper 1,800 ft consists of two layers, - the first layer has a thickness of 534 m (1,754 ft) with a resistivity of greater than 1,000 ohm-m, and the second layer has a resistivity of 6.8 ohm-m. All stations were interpreted with two-layer models for the PIA survey.



BLACKHAWK GEOSCIENCES, INC.

EXAMPLE
APPARENT RESISTIVITY CURVE
SOUNDING A
Potomac Investment Associates
Kaupuleha Project

PROJECT NO.: 90020 **FIGURE 3-1**

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		402.3	1320.0		
2611.14	534.7	-132.4	-434.3	0.2	0.2
6.77					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.44E-02	1.47E-02	-2.666	
2	1.10E-04	9.60E-03	1.02E-02	-5.452	
3	1.40E-04	7.38E-03	7.40E-03	-0.328	
4	1.77E-04	6.51E-03	5.94E-03	9.600	
5	2.20E-04	5.95E-03	5.02E-03	18.564	
6	2.80E-04	5.17E-03	4.32E-03	19.443	
7	3.55E-04	4.28E-03	3.74E-03	14.486	
8	4.43E-04	3.60E-03	3.24E-03	10.980	
9	5.64E-04	3.01E-03	2.78E-03	8.300	
10	7.13E-04	2.40E-03	2.38E-03	0.806	
11	8.81E-04	2.06E-03	2.05E-03	0.474	
12	8.90E-04	2.26E-03	2.04E-03	11.116	
13	1.10E-03	1.69E-03	1.75E-03	-3.419	
14	1.10E-03	1.95E-03	1.75E-03	11.480	
15	1.40E-03	1.54E-03	1.46E-03	5.666	
16	1.41E-03	1.32E-03	1.45E-03	-9.116	
17	1.77E-03	1.26E-03	1.21E-03	4.405	
18	1.80E-03	1.04E-03	1.19E-03	-12.590	
19	2.20E-03	1.02E-03	1.01E-03	1.001	
20	2.22E-03	8.25E-04	1.00E-03	-17.469	
21	2.80E-03	7.71E-04	8.16E-04	-5.530	
22	2.85E-03	6.41E-04	8.03E-04	-20.124	
23	3.55E-03	6.30E-04	6.54E-04	-3.761	
24	4.43E-03	5.14E-04	5.29E-04	-2.806	
25	5.64E-03	3.98E-04	4.11E-04	-3.196	
26	7.13E-03	3.07E-04	3.19E-04	-3.986	
27	8.81E-03	2.32E-04	2.50E-04	-7.463	
28	1.10E-02	1.77E-04	1.92E-04	-7.929	
29	1.41E-02	1.31E-04	1.40E-04	-6.918	
30	1.80E-02	9.49E-05	1.01E-04	-6.181	

R: 152. X: 0. Y: 153. DL: 305. REQ: 170. CF: 1.0000
TDHZ ARRAY, 30 DATA POINTS, RAMP: 205.0 MICROSEC, DATA: PTM-A
0404 002N 0002 Z OPR XTL H 6 8+100
Ch.21 = 0.205 Ch.22 = 0.089 Ch.23 = 21 Ch.24 =
RMS LOG ERROR: 4.21E-02, ANTILOG YIELDS 10.1893 %
EARLY TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

	P 1	F 2	T 1
P 1	1.00		
F 2	0.00	0.00	
T 1	0.00	0.00	1.00

BLACKHAWK GEOSCIENCES, INC.

EXAMPLE DATA SHEET
SOUNDING A
Potomac Investment Associates
Kaupuleha Project

PROJECT NO.: 90020 **FIGURE 3-2**

4.0 INTERPRETATION RESULTS

4.1 GENERAL

The objective of PIA and its ground water consultants is not to obtain the resistivity layering of the subsurface, but to infer from the resistivity information about the depth to salt water and the thickness of the basal fresh water lens. The translation of resistivity layering into hydrogeologic information is generally accomplished in two ways:

1. Using available knowledge about the relation between resistivity values and hydrogeology. For example, in the volcanic rocks of Hawaii rocks saturated with salt water will generally have resistivities less than 5 ohm-m. On the other hand, dry volcanic rocks can have very high resistivities (greater than 1,000 ohm-m).

2. Calibrating the geophysical interpretation at a well. In this case two wells were available for comparison. The approximate location of these wells is shown in Figure 2-1. The two wells are separated by less than 100 ft and show static water levels (head) of 6.9 ft and 12.6 ft. This large difference in head over such a short distance can only be explained by errors in a head measurement or major geologic structures (rifts, faults, etc.) which act to dam ground water flow.

Due to the large difference in head at the wells, this information could not be used to directly calibrate the TDEM soundings. The head information is useful as an approximate range for general comparisons. Sounding 1 of the KECI survey, located about 100 ft lower in elevation and about 500 ft to the north of the wells, showed an approximate head of 7.2 ft. This value is in good general agreement with the head values from the wells. A value of 6.77 ohm-m was selected from this information as the resistivity of saline water saturated volcanics in the study area.

The results of the TDEM interpretations from the PIA and KECI surveys are incorporated and presented as a geoelectric cross-section in Figure 4-1 and in Table 4-1.

4.2 GEOELECTRIC SECTION

In the geoelectric section (Fig. 4-1) layers with similar resistivities have been linked together. Beneath soundings 2, 3 and 4 a three-layer section is interpreted, and beneath sounding 1 a two-layer section was interpreted in the KECI survey. PIA soundings A and B are also interpreted as two layers.

In the geoelectric section the near surface layer (740 to 5585 ohm-m) is interpreted to represent unsaturated and fresh/brackish water saturated volcanics. Generally, it is difficult to discriminate between dry volcanics grading into fresh water or brackish water (less than 500 ppm chloride) saturated volcanics. The reason is that, in addition to salinity, changes in porosity and lithology also influence formation resistivity, particularly at low values of chloride concentration. The lowest layer in the section (6.8 ohm-m) represents saline water saturated volcanics. The second layer beneath soundings 2, 3 and 4 exhibits intermediate resistivities (28 to 43 ohm-m). These intermediate resistivities may be caused by one or more of the following factors

- alteration of volcanics
- increased salinity
- presence of clays or ash flows.

Due to the proximity of Puu Nahaha to these soundings it is more likely that this intermediate layer is related to either alteration of the volcanics or ash flows, and not to an increase in salinity.

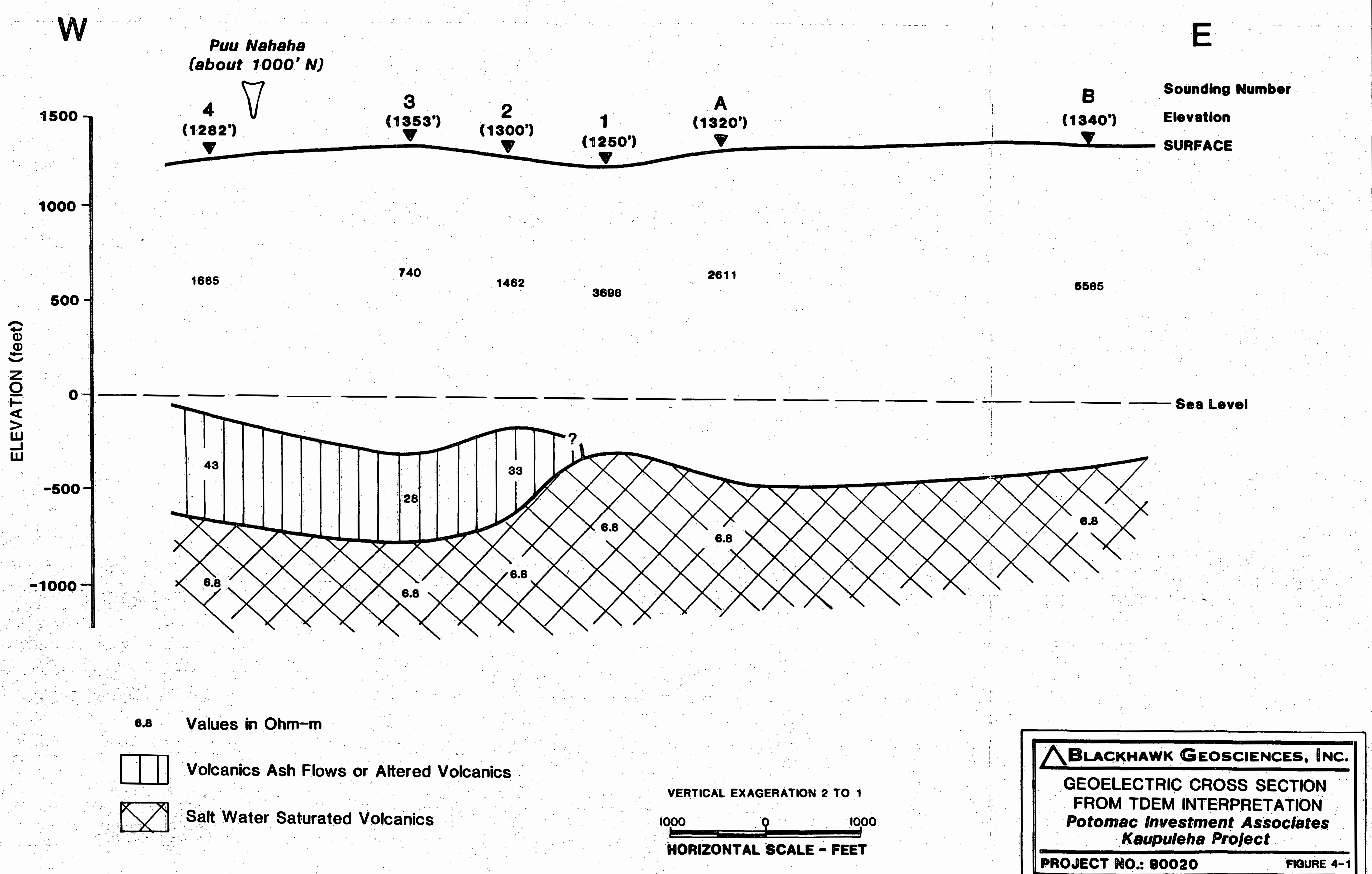
Sounding C was located in a steep terrain area near the downhill side of Route 190 as shown in Figure 2-1. The results of this sounding indicate a depth of saline water saturated volcanics of 352 ft below sea level, a head of 8.8 ft, and a fresh/brackish water lens thickness of 361 ft.

4.3 HYDROGEOLOGIC INTERPRETATION

Table 4-1 below shows the calculated head of fresh/brackish water and thickness of the fresh/brackish water lens. The bottom of the fresh/brackish water lens is obtained directly from the geoelectric section (Fig. 4-1), and the top of the fresh water lens (head) is calculated from the Ghyben-Herzberg relation. The thickest fresh/brackish water lens (796 ft) is interpreted to occur near sounding 3 of the KECI survey.

Table 4-1. Hydrogeologic information derived from TDEM soundings

Sounding #	Surface Elevation (ft)	Head of Fresh/Brackish Water Above Sea Level (Water Table) (ft)	Minimum Thickness of Fresh/Brackish Water Lens (ft)
1 (KECI)	1250	7.2	296
2 (KECI)	1300	16.7	686
3 (KECI)	1353	19.4	796
4 (KECI)	1282	16.7	684
A (PIA)	1320	10.8	445
B (PIA)	1340	8.6	352
C (PIA)	1900	8.8	360


W
E
Puu Nahaha
(about 1000' N)
Sounding Number
Elevation
SURFACE
4
(1282')
3
(1353')
2
(1300')
1
(1250')
A
(1320')
B
(1340')
1500
1000
500
0
-500
-1000
ELEVATION (feet)
1665
740
1462
3698
2611
5585
Sea Level
?
43
28
33
6.8
Values in Ohm-m
Volcanics Ash Flows or Altered Volcanics
Salt Water Saturated Volcanics
VERTICAL EXAGERATION 2 TO 1
1000
0
1000
HORIZONTAL SCALE - FEET
BLACKHAWK GEOSCIENCES, INC.
GEOELECTRIC CROSS SECTION
FROM TDEM INTERPRETATION
Potomac Investment Associates
Kaupuleha Project
PROJECT NO.: 90020
FIGURE 4-1

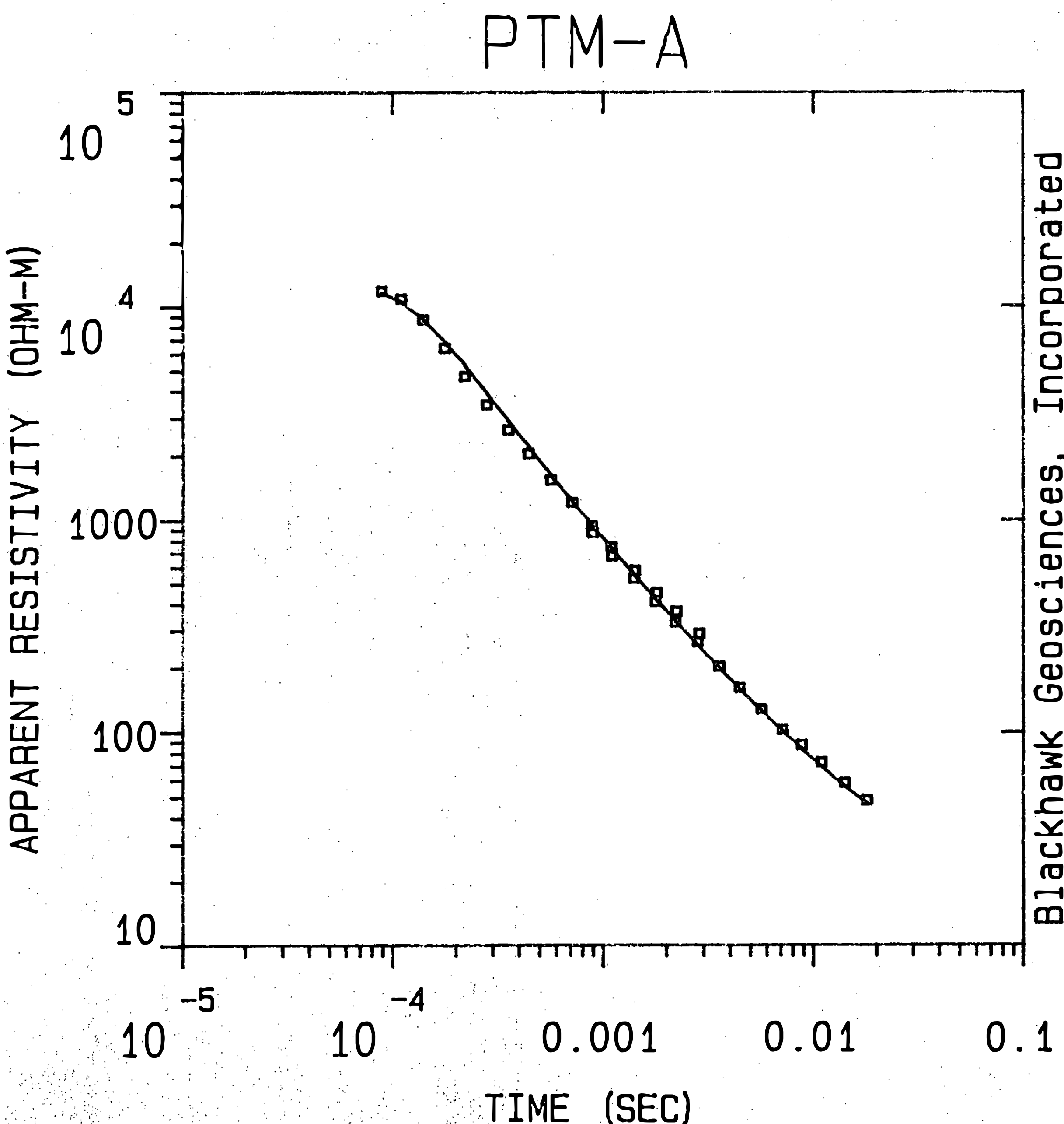
5.0 CONCLUSIONS AND RECOMMENDATIONS

The TDEM survey indicates that in the area covered by the four soundings of the KECI survey and the 3 soundings from the PIA survey, the largest thickness of fresh/brackish water occurs beneath sounding 3 (thickness of approximately 796 ft). At this station the head of fresh/brackish water is expected to be about 19 ft.

The geoelectric section for the 7 soundings (Fig. 4-1) shows that beneath soundings 2, 3 and 4 an intermediate resistivity unit was detected. This unit is expected to be caused by fresh/brackish water saturated ash flows or altered volcanics which may affect permeability and subsequently ground water yield. A slight possibility exists that the unit may be caused by an increase in salinity.

The rapid change in head between soundings 1 and 2 suggests that ground water damming structures or major lithologic changes occur in this vicinity.

The results from the recent PIA survey are consistent with the results of the KECI survey. To confirm the existence of such geologic structures, additional soundings on lines parallel and perpendicular to the expected structure are recommended.



MODEL:

2611. OHM-M — 535. M

6.77 OHM-M

% ERROR: 10.2
CALIBRATION: 1
OFFSET: 152. M
RAMP: 205.0

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		402.3	1320.0		
2611.14	534.7	-132.4	-434.3	0.2	0.2
6.77					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	1.44E-02	1.47E-02	-2.666	
2	1.10E-04	9.60E-03	1.02E-02	-5.452	
3	1.40E-04	7.38E-03	7.40E-03	-0.328	
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9	5.64E-04	3.01E-03	2.78E-03	8.300	
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13	1.10E-03	1.69E-03	1.75E-03	-3.419	
14	1.10E-03	1.95E-03	1.75E-03	11.460	
15	1.40E-03	1.54E-03	1.46E-03	5.666	
16	1.41E-03	1.32E-03	1.45E-03	-9.116	
17	1.77E-03	1.26E-03	1.21E-03	4.405	
18	1.80E-03	1.04E-03	1.19E-03	-12.590	
19	2.20E-03	1.02E-03	1.01E-03	1.001	
20	2.22E-03	8.25E-04	1.00E-03	-17.469	
21	2.80E-03	7.71E-04	8.16E-04	-5.530	
22	2.85E-03	6.41E-04	8.03E-04	-20.124	
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26	7.13E-03	3.07E-04	3.19E-04	-3.986	
27	8.81E-03	2.32E-04	2.50E-04	-7.463	
28	1.10E-02	1.77E-04	1.92E-04	-7.929	
29	1.41E-02	1.31E-04	1.40E-04	-6.918	
30	1.80E-02	9.49E-05	1.01E-04	-6.181	

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Ch.21 = 0.205 Ch.22 = 0.089 Ch.23 = 21 Ch.24 =
RMS LOG ERROR: 4.21E-02, ANTILOG YIELDS 10.1893 %
EARLY TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

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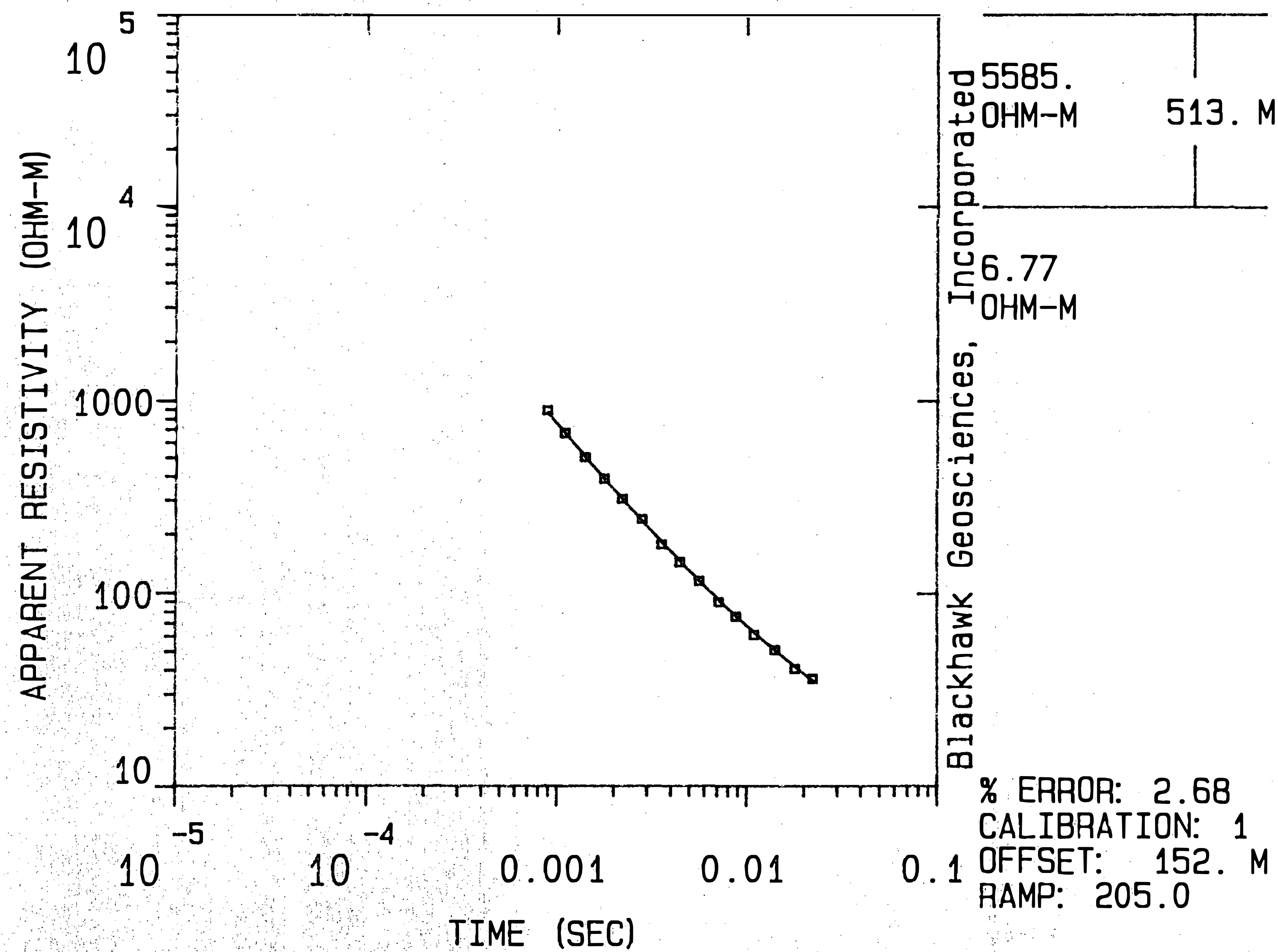
F 2	0.00	0.00	
T 1	0.00	0.00	1.00
	P 1	F 2	T 1

PTM-B


MODEL:
5585.
OHM-M
513. M
6.77
OHM-M
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
TIME (SEC)
10^-5
10^-4
0.001
0.01
0.1
Blackhawk Geosciences, Incorporated
% ERROR: 2.68
CALIBRATION: 1
OFFSET: 152. M
RAMP: 205.0

PTM-B

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		408.4	1340.0		
5584.62	513.0	-104.6	-343.2	0.1	0.1
6.77					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-04	2.20E-03	2.29E-03	-3.951	
2	1.10E-03	1.95E-03	1.97E-03	-0.859	
3	1.40E-03	1.65E-03	1.64E-03	0.588	
4	1.77E-03	1.35E-03	1.37E-03	-1.094	
5	2.20E-03	1.13E-03	1.14E-03	-1.002	
6	2.80E-03	8.88E-04	9.21E-04	-3.575	
7	3.55E-03	7.73E-04	7.41E-04	4.322	
8	4.43E-03	6.06E-04	5.95E-04	1.810	
9	5.64E-03	4.63E-04	4.65E-04	-0.393	
10	7.13E-03	3.72E-04	3.61E-04	3.278	
11	8.81E-03	2.83E-04	2.83E-04	0.250	
12	1.10E-02	2.27E-04	2.19E-04	3.736	
13	1.41E-02	1.58E-04	1.59E-04	-0.681	
14	1.80E-02	1.21E-04	1.17E-04	3.472	
15	2.22E-02	8.49E-05	8.83E-05	-3.814	

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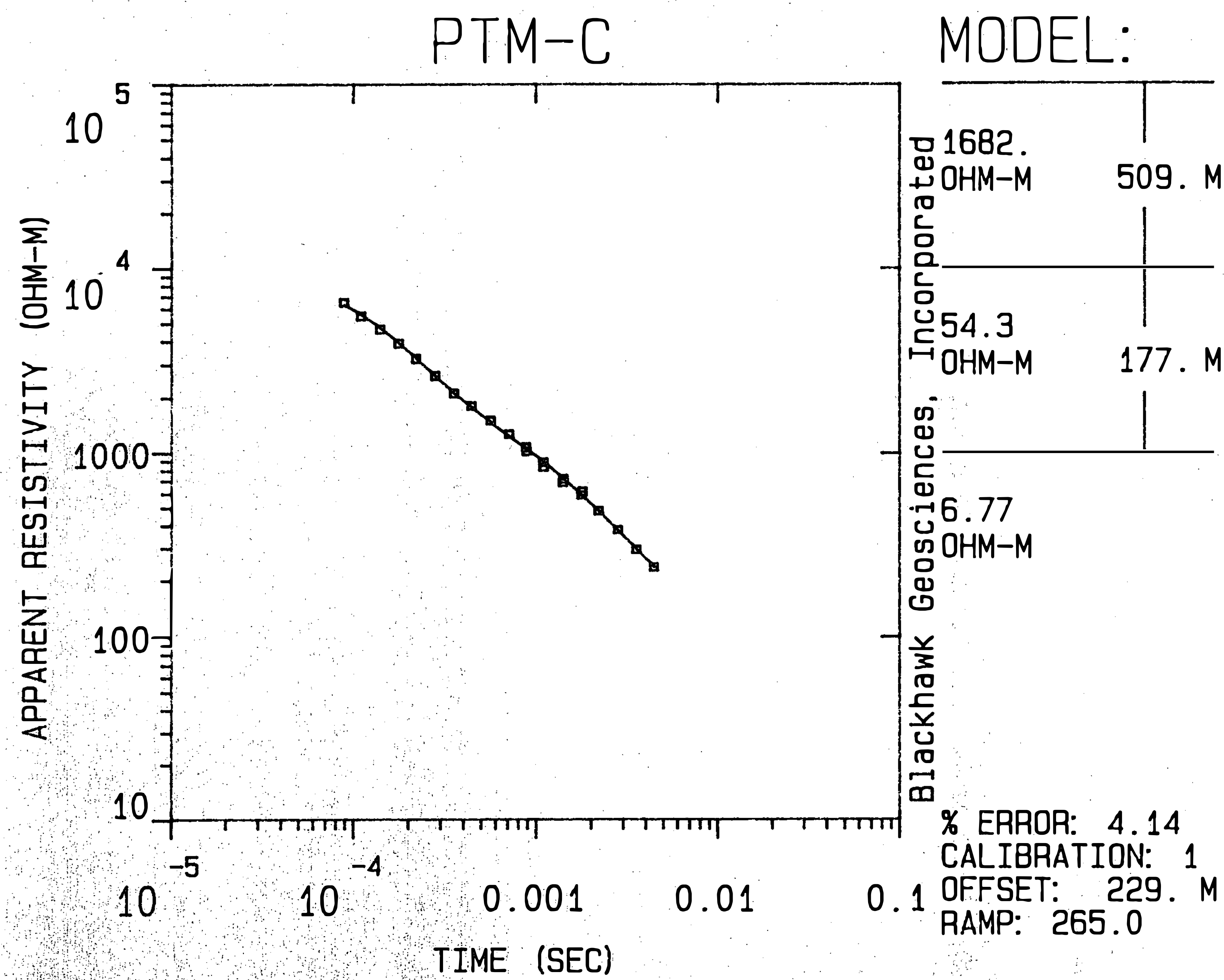
0404 003N 0003 Z OPR XTL L 7 10+100
Ch.21 = 0.205 Ch.22 = 0.89 Ch.23 = 20 Ch.24 = 9
RMS LOG ERROR: 1.15E-02, ANTILOG YIELDS 2.6843 %
EARLY TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.06		
F 2	0.00	0.00	
T 1	0.00	0.00	1.00
	P 1	F 2	T 1



PTM-C
MODEL:
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^{-5}
10^{-4}
0.001
0.01
0.1
TIME (SEC)
Blackhawk Geosciences, Incorporated
1682.
OHM-M
509. M
54.3
OHM-M
177. M
6.77
OHM-M
% ERROR: 4.14
CALIBRATION: 1
OFFSET: 229. M
RAMP: 265.0

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		579.1	1900.0		
1682.15	509.3	69.8	229.1	0.3	0.3
54.30	177.1	-107.3	-352.1	3.3	3.6
6.77					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	6.48E+03	6.31E+03	2.681	
2	1.10E-04	5.46E+03	5.58E+03	-2.160	
3	1.40E-04	4.63E+03	4.73E+03	-1.984	
4	1.77E-04	3.88E+03	3.91E+03	-0.811	
5	2.20E-04	3.23E+03	3.24E+03	-0.452	
6	2.80E-04	2.62E+03	2.61E+03	0.427	
7	3.55E-04	2.11E+03	2.11E+03	-0.199	
8	4.43E-04	1.81E+03	1.77E+03	2.306	
9	5.64E-04	1.50E+03	1.47E+03	2.460	
10	7.13E-04	1.27E+03	1.23E+03	3.212	
11	8.81E-04	1.07E+03	1.05E+03	1.954	
12	8.90E-04	1.02E+03	1.05E+03	-2.511	
13	1.10E-03	8.89E+02	8.96E+02	-0.794	
14	1.10E-03	8.34E+02	8.93E+02	-6.614	
15	1.40E-03	6.88E+02	7.25E+02	-5.153	
16	1.41E-03	7.20E+02	7.20E+02	0.067	
17	1.77E-03	5.89E+02	5.87E+02	0.371	
18	1.80E-03	6.15E+02	5.79E+02	6.195	
19	2.20E-03	4.80E+02	4.77E+02	0.730	
20	2.80E-03	3.78E+02	3.75E+02	0.774	
21	3.55E-03	2.95E+02	2.96E+02	-0.342	
22	4.43E-03	2.37E+02	2.37E+02	-0.047	

R: 229. X: 0. Y: 229. DL: 457. REQ: 254. CF: 1.0000
TDHZ ARRAY, 22 DATA POINTS, RAMP: 265.0 MICROSEC, DATA: PTM-C
0304 001N 0001 Z OPR XTL L 6 10+100
Ch.21 = 0.265 Ch.22 = 0.89 Ch.23 = 18.5 Ch.24 =
RMS LOG ERROR: 1.76E-02, ANTILOG YIELDS 4.1432 %
LATE TIME PARAMETERS

* Blackhawk Geosciences, Incorporated *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	1.00				
P 2	0.00	1.00			
F 3	0.00	0.00	0.00		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	0.00	0.00	1.00
	P 1	P 2	F 3	T 1	T 2

GEOPHYSICAL SURVEYS FOR
GROUND WATER EVALUATION
KULOLO QUADRANGLE, HAWAII

KIHOLO

GEOPHYSICAL SURVEYS
FOR
GROUND WATER EVALUATION
KULOLO QUADRANGLE, HAWAII

Prepared For:

Kajima Engineering and Construction, Inc.
Bougainvillea Plaza, Suite 303
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Kailua-Kona, Hawaii 96740

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Blackhawk Geosciences, Inc.
17301 West Colfax Avenue, Suite 170
Golden, CO 80401

February 15, 1990

(Our Project #90005)

Table of Contents

1.0 INTRODUCTION

KIHOLO

This report contains the results of a geophysical survey to assist the evaluation of fresh water resources near Puu Nahaha, Kulolo Quadrangle, on the Island of Hawaii. The work was performed for Kajima Engineering and Construction, Inc. (KECI) on January 24 and 25, 1990.

The objectives for the geophysical survey can be understood from the hydrogeologic cross-section, typical of a volcanic island, shown in Figure 1-1. The volcanic rocks are generally highly permeable and rainfall rapidly infiltrates into the ground and migrates downward to the water table, and eventually discharges into the ocean. Fresh water in these settings is found in two environments.

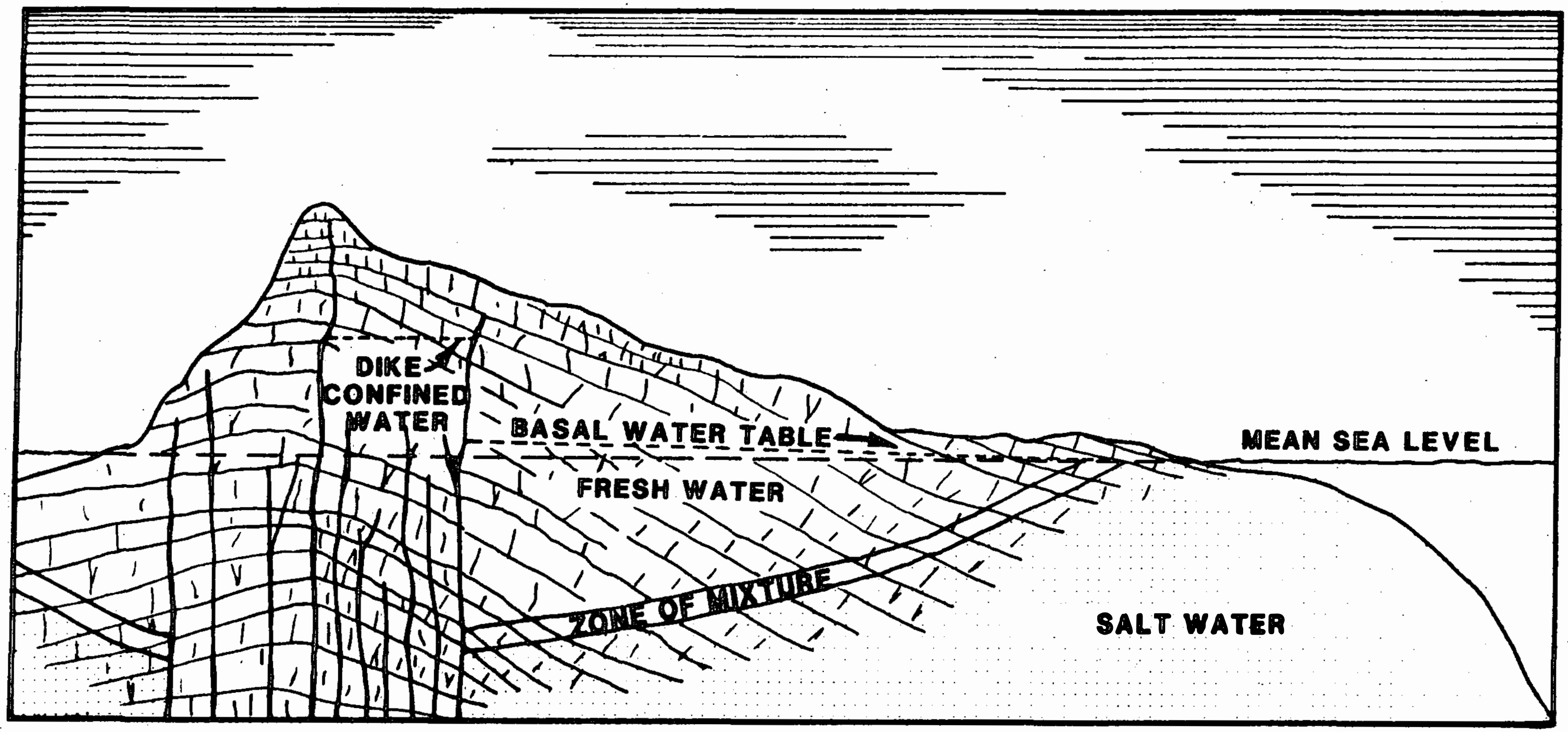
1. <u>Dike confined waters</u>. Above the rift zone intrusive dikes originating from a magma source below can form ground water dams, and behind these natural dams significant quantities of ground water can be stored.

2. <u>Basal fresh water</u>. The high permeability of the volcanic rocks allows sea water to enter freely under the island, and a delicate balance is reached where a lens of fresh water floats on sea water. The Ghyben-Herzberg relation states that for every foot of fresh water head above sea level there will be 40 ft of fresh water below sea level.

The basal water resource was the focus in the investigations for KECI. The drilling depth to the basal fresh water lens rapidly increases with elevation, and the objective of geophysical surveys is to determine the drilling depth to fresh water and the thickness of the fresh water lens. The impetus for using geophysics is that the cost of a geophysical station is about one-five-hundredth of the cost of drilling a well at elevations above 1,000 ft. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths.

The geophysical method employed was time domain electromagnetic (TDEM) soundings. This method was selected because it has proven effective in prior surveys in similar settings in Hawaii.

The specific objectives of the geophysical survey near Puu Nahaha were (i) to calibrate the TDEM soundings near existing wells, and (ii) to derive the thickness of the basal fresh water zone near several proposed drill sites nearby.



BLACKHAWK GEOSCIENCES, INC.

SCHEMATIC HYDRO-GEOLOGIC CROSS SECTION

Kajima Engineering and Construction, Inc.

PROJECT NO.: 90005

FIGURE 1-1

2.0 LOGISTICS AND DATA ACQUISITION

A brief description of the fundamentals of TDEM is given in Appendix A. Briefly, the logistics of a TDEM measurement consist of:

1. Laying out a square loop of insulated wire. A generator placed in the loop is used to drive current pulses through this closed loop. The dimensions of the square loops employed depend on the exploration depth requirements. The dimensions of the loops used for KECI were 1,000 ft by 1,000 ft on each side.

   Where possible, transmitter loop wires were positioned with at least one wire near roads and trails. Loops 1 and 2 were positioned downhill from the existing wells to avoid possible interference from the borehole casing.

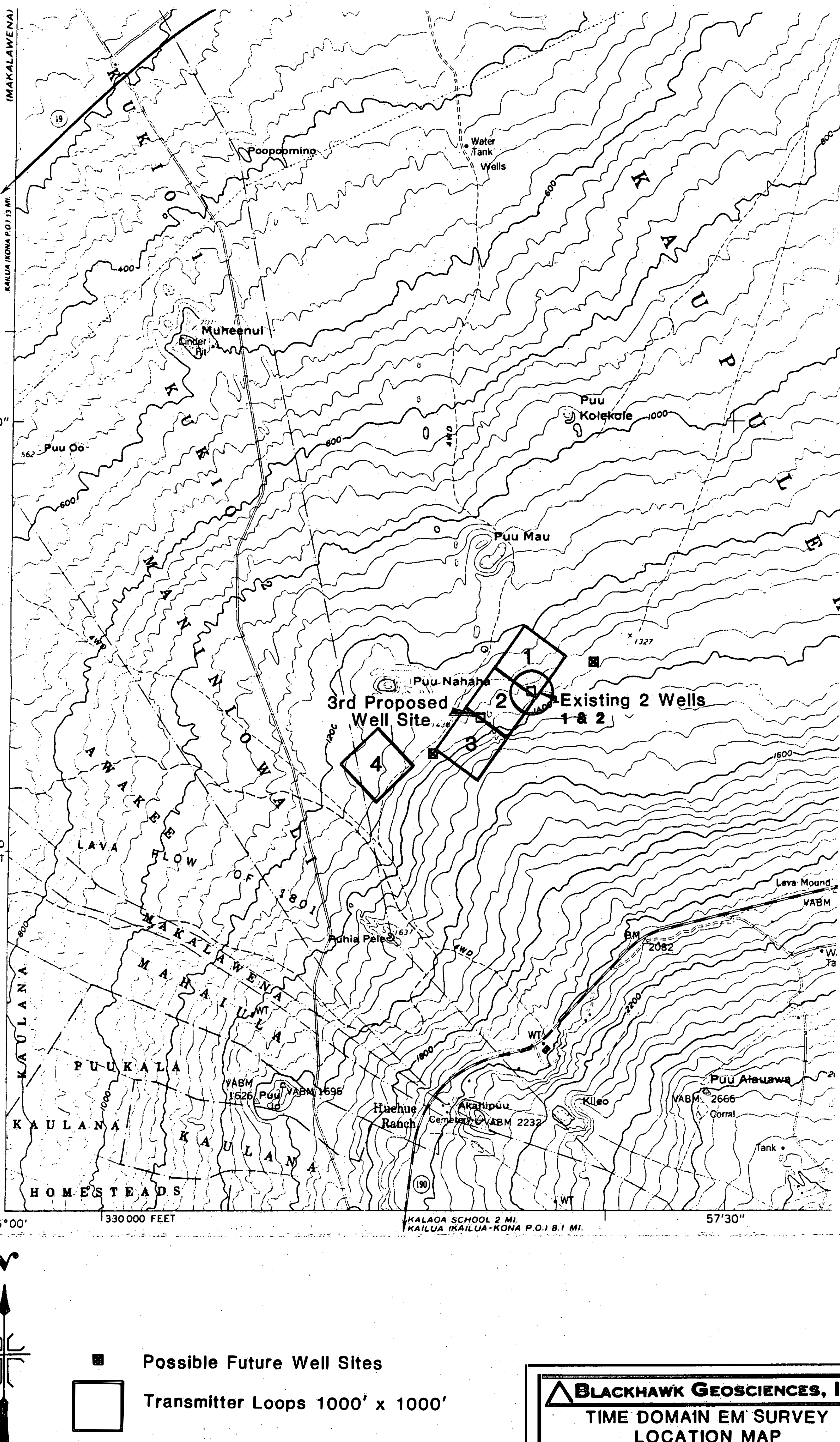
2. Making a measurement with a receiver in the center of the loop. The data acquired at each station was stored in the field on a solid state data logger and subsequently dumped to a computer at the end of each field day. The data acquired at each station usually consisted of measurements at several receiver gain settings and transmitter frequencies in order to assure data quality and to obtain data over the largest time range possible. Data quality was generally very good.

During the day and a half of field work 4 stations (soundings) were completed. A daily log of field activity is given in Table 2-1. Figure 2-1 shows the location of the soundings conducted for KECI and the locations of existing and proposed well sites. The position of the TDEM soundings was constrained by available road access.

Table 2-1. Daily log of field activities

Date (1990)	Activity
January 18	Meeting with KECI personnel and site check.
January 24	Measurement sounding 1.
January 25	Measurement of soundings 2, 3 and 4.
January 26-27	Demobilize from Kailua-Kona, HI to Golden, CO.

Kulolo Quadrangle
Island of Hawaii



N

Possible Future Well Sites

Transmitter Loops 1000' x 1000'

2000 0 2000
SCALE - FEET

BLACKHAWK GEOSCIENCES, INC.

TIME DOMAIN EM SURVEY
LOCATION MAP

Kajima Engineering and Construction Inc.

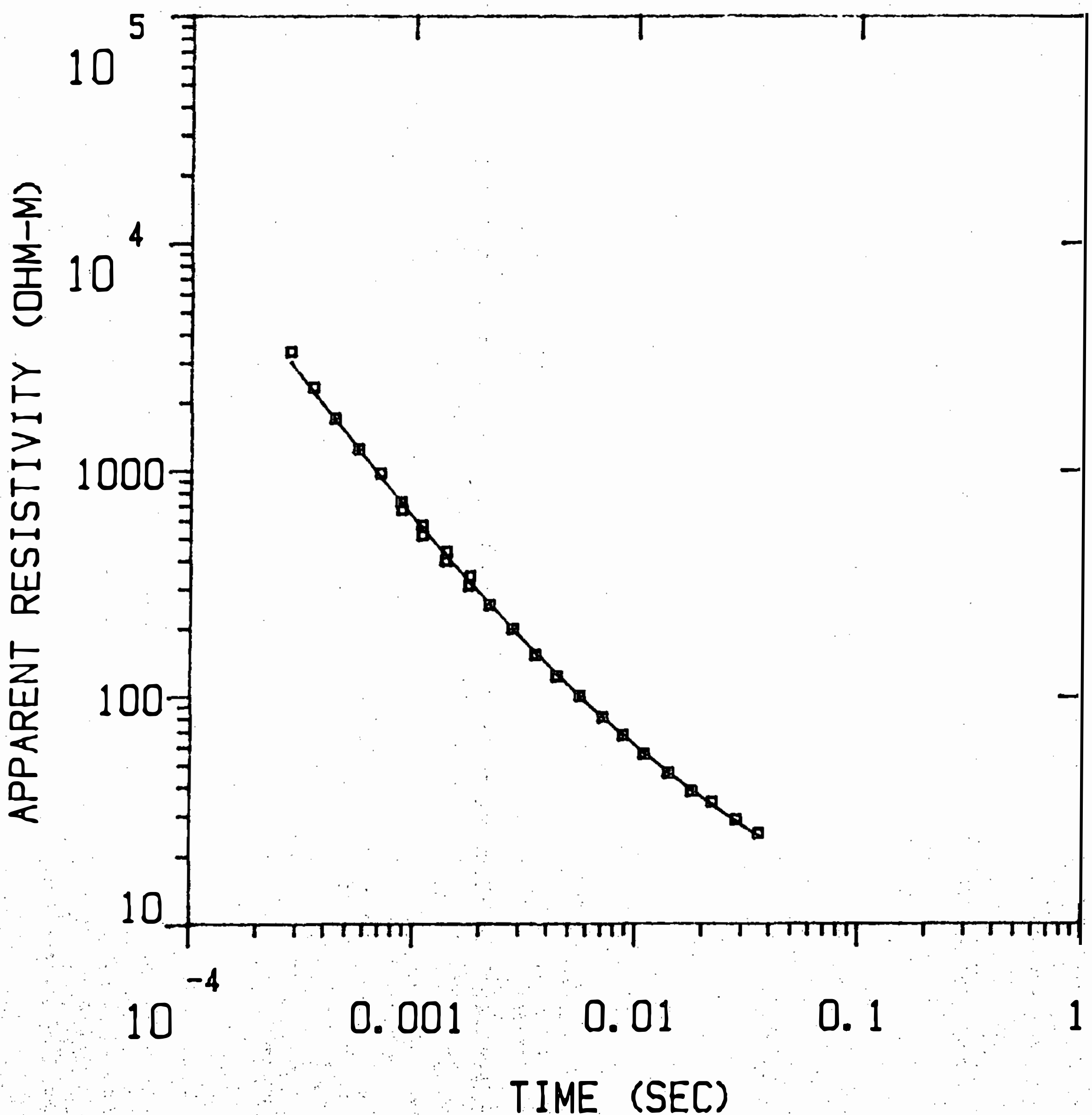
PROJECT NO.: 90005 FIGURE 2-1

3.0 DATA PROCESSING

The objective of data processing is to derive from the TDEM measurements in the center of the loop the resistivity layering in the earth. The procedures of data processing are discussed in Appendix A. The results from data processing for each station are contained in Appendix B. An example data set is given in Figures 3-1 and 3-2 for the station near the existing well sites (loop 1). Figure 3-1 shows the measured data points (in terms of apparent resistivity) superimposed on a solid line. The solid line represents the computed behavior of the true resistivity layering shown on the right. Figure 3-2 lists in column 4 the error between measured and computed data in each time gate.

Figure 3-1 shows that the resistivity layering in the upper 1,600 ft consists of two layers, - the first layer has a thickness of 469 m (1,539 ft) with a resistivity of greater than 1,000 ohm-m, and the second layer has a resistivity of 6.8 ohm-m. At the other stations the data was interpreted with three layer models.

J1



MODEL:

3693.
OHM-M 469. M

6.77
OHM-M

BLACKHAWK GEOSCIENCES, INC.

EXAMPLE
APPARENT RESISTIVITY CURVE

Kajima Engineering and Construction, Inc.

PROJECT NO.: 90005 **FIGURE 3-1**

% ERROR: 6.14
CALIBRATION: 1
OFFSET: 152. M
RAMP: 210.0
Blackhawk Geosciences

J1

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		381.0	1250.0		
3693.01	469.2	-88.2	-289.4	0.1	0.1
6.77					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.80E-04	3.36E+03	3.04E+03	10.652	
2	3.55E-04	2.34E+03	2.24E+03	4.645	
3	4.43E-04	1.70E+03	1.69E+03	0.394	
4	5.64E-04	1.24E+03	1.25E+03	-0.664	
5	7.13E-04	9.73E+02	9.40E+02	3.512	
6	8.81E-04	7.28E+02	7.28E+02	-0.018	
7	8.90E-04	6.71E+02	7.20E+02	-6.679	
8	1.10E-03	5.74E+02	5.64E+02	1.757	
9	1.10E-03	5.19E+02	5.62E+02	-7.563	
10	1.40E-03	4.01E+02	4.26E+02	-5.770	
11	1.41E-03	4.41E+02	4.22E+02	4.609	
12	1.77E-03	3.12E+02	3.27E+02	-4.602	
13	1.80E-03	3.44E+02	3.22E+02	6.632	
14	2.20E-03	2.55E+02	2.59E+02	-1.652	
15	2.80E-03	2.00E+02	2.00E+02	-0.298	
16	3.55E-03	1.53E+02	1.57E+02	-2.774	
17	4.43E-03	1.23E+02	1.27E+02	-2.962	
18	5.64E-03	1.01E+02	1.01E+02	0.174	
19	7.13E-03	8.14E+01	8.17E+01	-0.310	
20	8.81E-03	6.77E+01	6.79E+01	-0.186	
21	1.10E-02	5.59E+01	5.67E+01	-1.421	
22	1.41E-02	4.63E+01	4.66E+01	-0.754	
23	1.80E-02	3.85E+01	3.89E+01	-1.169	
24	2.22E-02	3.45E+01	3.36E+01	2.618	
25	2.85E-02	2.89E+01	2.84E+01	1.716	
26	3.60E-02	2.52E+01	2.44E+01	3.026	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 26 DATA POINTS, RAMP: 210.0 MICROSEC, DATA: J1

RMS LOG ERROR: 2.59E-02, ANTILOG YIELDS 6.1356 %
LATE TIME PARAMETERS

* Blackhawk Geoscienc

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	0.10		
P 2	-0.03	0.96	
T 1	0.01	0.00	1.00
	P 1	P 2	T 1

BLACKHAWK GEOSCIENCES, INC.

EXAMPLE
DATA SHEET SOUNDING #1
Kajima Engineering and Construction, Inc.

PROJECT NO.: 90005 FIGURE 3-2

4.0 INTERPRETATION RESULTS

4.1 GENERAL

The objective of KECI and its ground water consultants is not to obtain the resistivity layering of the subsurface, but to infer from the resistivity information about the depth to salt water and the thickness of the basal fresh water lens. The translation of resistivity layering into hydrogeologic information is generally accomplished in two ways:

1. Using available knowledge about the relation between resistivity values and hydrogeology. For example, in the volcanic rocks of Hawaii rocks saturated with salt water will have resistivities less than 5 ohm-m. On the other hand, dry volcanic rocks can have very high resistivities (greater than 1,000 ohm-m).

2. Calibrating the geophysical interpretation at a well. In this case two wells were available for comparison. The approximate location of these wells is shown in Figure 2-1. The two wells are separated by less than 100 ft and show static water levels (head) of 6.9 ft and 12.6 ft. This large difference in head over such a short distance can only be explained by errors in a head measurement or major geologic structures (rifts, faults, etc.) which act to dam ground water flow.

DON'T GIVE TOO MUCH CREDENCE TO THIS DIFFERENCE

Due to the large difference in head at the wells, this information could not be used to directly calibrate the TDEM soundings. The head information is useful as an approximate range for general comparisons. Sounding 1, located about 100 ft lower in elevation and about 500 ft to the north of the wells shows an approximate head of 7.2 ft. This value is in good general agreement with the head values from the wells.

The results of the TDEM interpretations are presented as geoelectric and hydrogeologic sections in Figures 4-1 and 4-2.

4.2 GEOELECTRIC SECTION

In the geoelectric section (Fig. 4-1) layers with similar resistivities have been linked together. Beneath soundings 2, 3 and 4 a three layer section is interpreted and beneath sounding 1 a two layer section is interpreted.

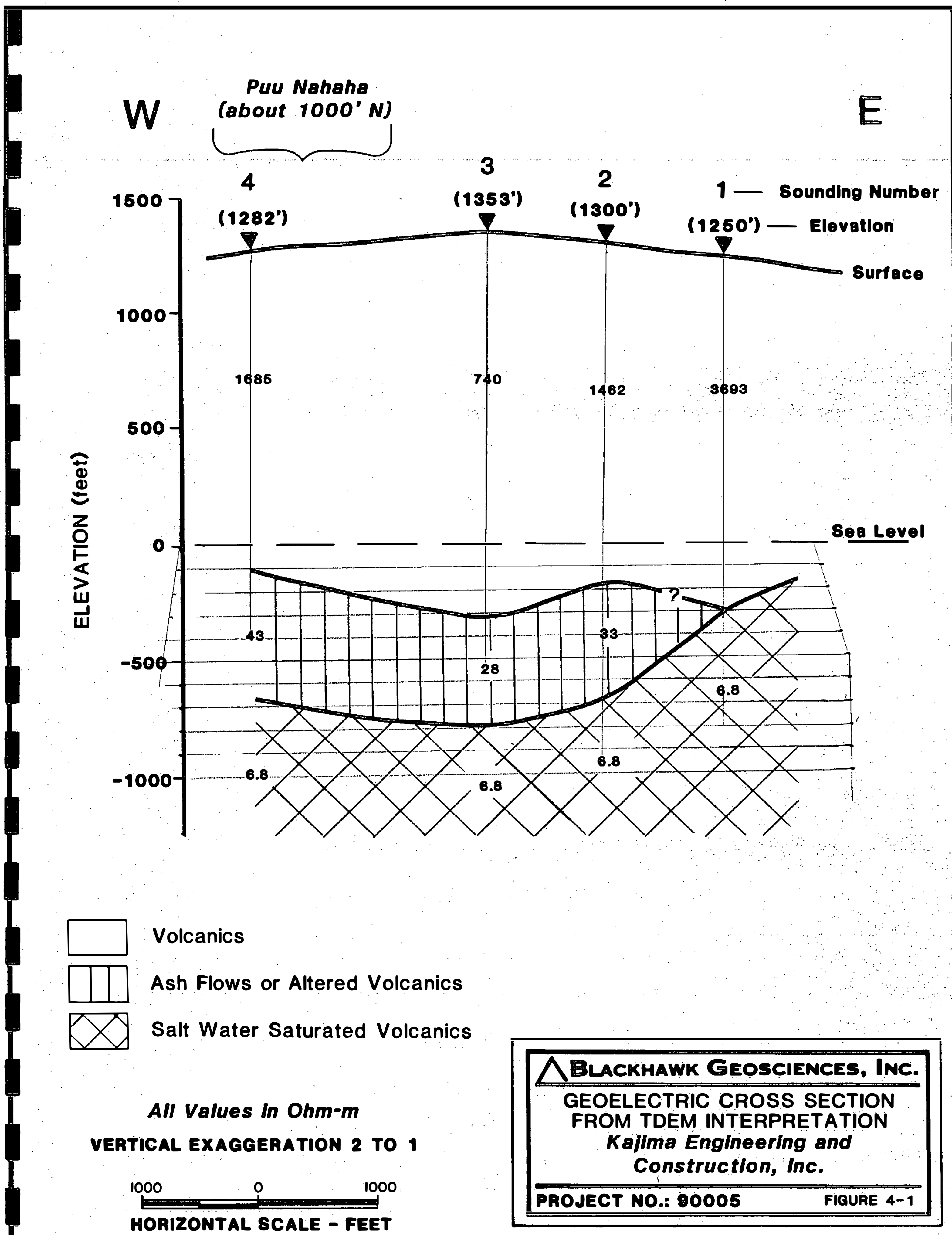
In the geoelectric section the near surface layer (740 to 3693 ohm-m) is interpreted to represent unsaturated and fresh/brackish water saturated volcanics. Generally, it is difficult to discriminate between dry and fresh water or brackish water (less than 1,000 ppm chloride) saturated volcanics. The reason is that, in addition to salinity, changes in porosity and lithology also influence formation resistivity, particularly at low values of chloride concentration. The lowest layer in the section (6.8 ohm-m) represents saline water saturated volcanics. The second layer beneath soundings 2, 3 and 4 exhibits intermediate resistivities (28 to 43 ohm-m). These intermediate resistivities may be caused by one or more of the following factors

- alteration of volcanics
- increased salinity
- presence of clays or ash flows.

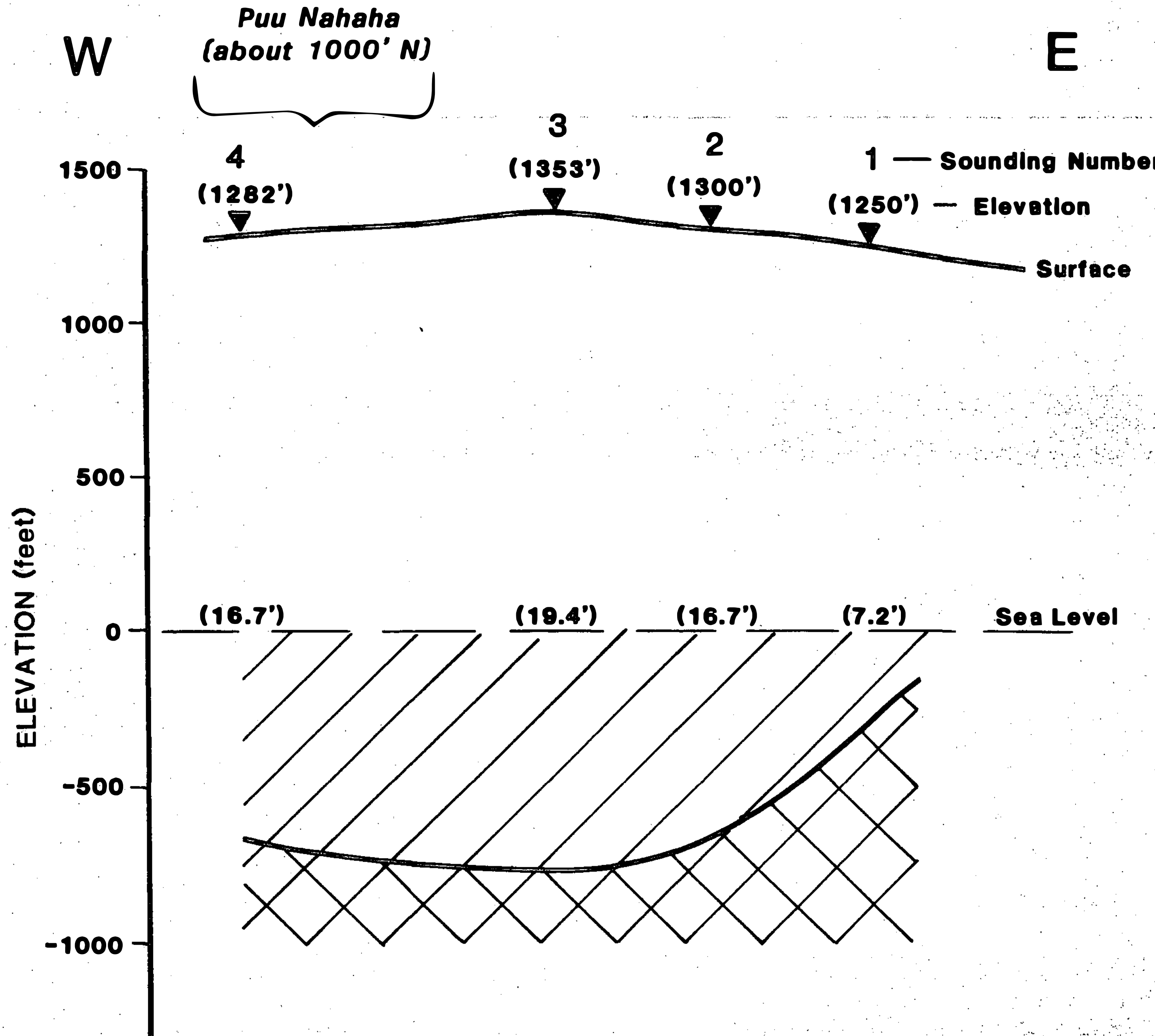
Due to the proximity of Puu Nahaha to these soundings it is more likely that this intermediate layer is related to either alteration of the volcanics or ash flows and not to an increase in salinity.

4.3 HYDROGEOLOGIC SECTION

In the hydrogeologic section (Fig. 4-2) the head of fresh/brackish water and thickness of the fresh/brackish water lens is shown. The bottom of the fresh/brackish water lens is obtained directly from the geoelectric section (Fig. 4-1), and the top of the fresh water lens (head) is calculated from the Ghyben-Herzberg relation. In this figure a rapid increase in thickness of fresh/brackish water lens is interpreted between soundings 1 and 2. The thickest fresh/brackish water lens (796 ft) is interpreted to occur near sounding 3.



W
E
Puu Nahaha (about 1000' N)
4
(1282')
3
(1353')
2
(1300')
1 — Sounding Number
(1250') — Elevation
Surface
1500
1000
500
0
-500
-1000
ELEVATION (feet)
1685
740
1462
3693
Sea Level
43
28
33
6.8
6.8
6.8
6.8
?
Volcanics
Ash Flows or Altered Volcanics
Salt Water Saturated Volcanics
All Values in Ohm-m
VERTICAL EXAGGERATION 2 TO 1
1000 0 1000
HORIZONTAL SCALE - FEET
BLACKHAWK GEOSCIENCES, INC.
GEOELECTRIC CROSS SECTION FROM TDEM INTERPRETATION
Kajima Engineering and Construction, Inc.
PROJECT NO.: 90005
FIGURE 4-1



Salt Water

Fresh/Brackish Water

(16.2') Calculated Elevation of Top of Fresh/Brackish Water

All Values In Ohm-m

VERTICAL EXAGGERATION 2 TO 1

1000 0 1000

HORIZONTAL SCALE - FEET

BLACKHAWK GEOSCIENCES, INC.

HYDROGEOLOGIC CROSS SECTION FROM TDEM INTERPRETATION

Kajima Engineering and Construction, Inc.

PROJECT NO.: 90005 **FIGURE 4-2**

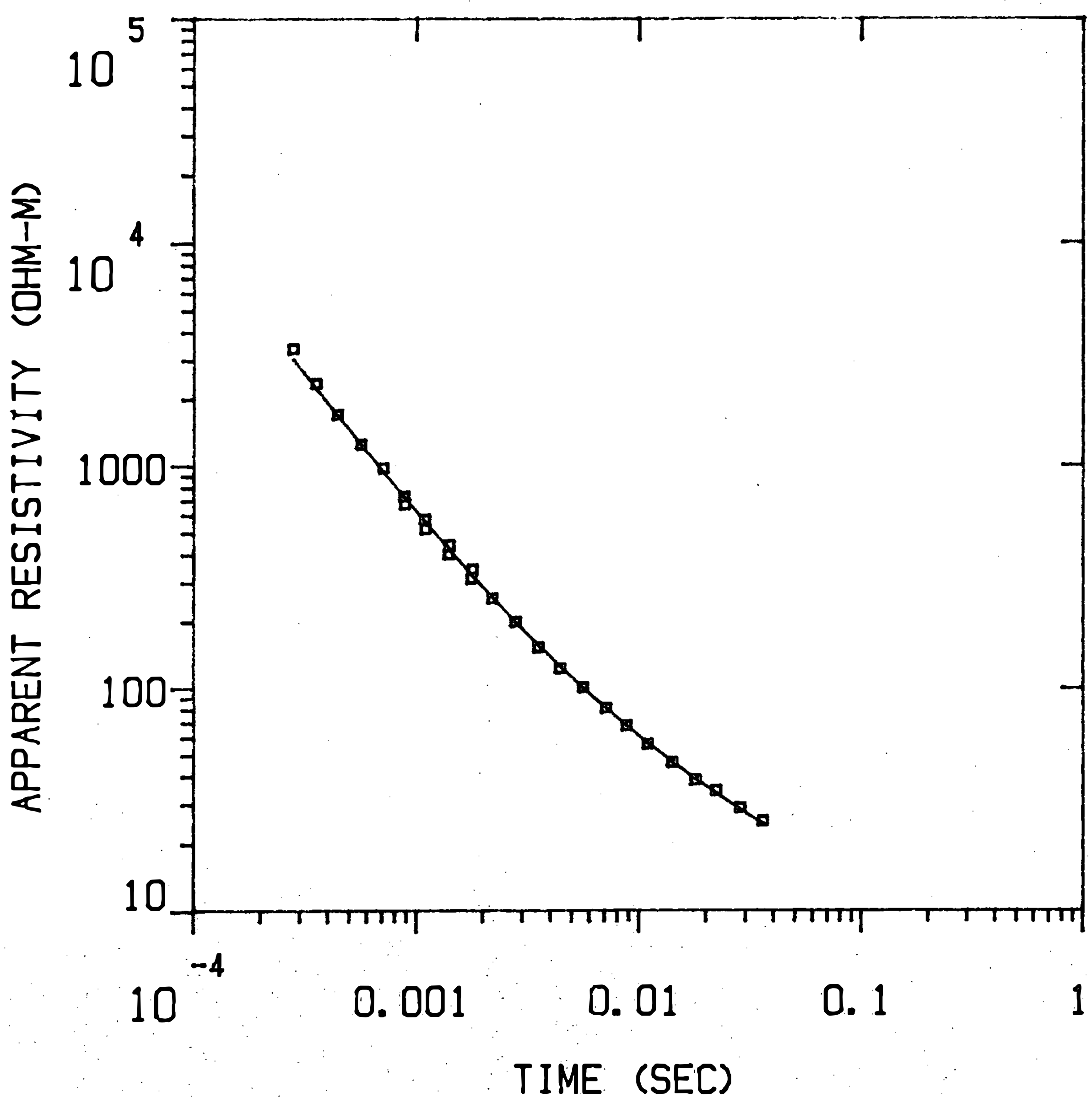
5.0 CONCLUSIONS AND RECOMMENDATIONS

The TDEM survey indicates that in the area covered by the four soundings the largest thickness of fresh/brackish water occurs beneath sounding 3 (thickness of approximately 796 ft). At this station the head of fresh/brackish water is expected to be about 19 ft.

The geoelectric section for the four soundings (Fig. 4-1) shows that beneath soundings 2, 3 and 4 an intermediate resistivity unit was detected. This unit is expected to be caused by fresh/brackish water saturated ash flows or altered volcanics which may affect permeability and subsequently ground water yield. A slight possibility exists that the unit may be caused by an increase in salinity.

The rapid change in head between soundings 1 and 2 suggests that ground water damming structures or major lithologic changes occur in this vicinity. To confirm the existence of such geologic structures, additional soundings on lines parallel and perpendicular to the expected structure are recommended.

J1



MODEL:

3693.
OHM-M

469. M

6.77
OHM-M

% ERROR: 6.14
CALIBRATION: 1
OFFSET: 152. M
RAMP: 210.0
Blackhawk Geosciences

MODEL: 2 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		381.0	1250.0		
3693.01	469.2	-88.2	-289.4	0.1	0.1
6.77					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	2.80E-04	3.36E+03	3.04E+03	10.652	
2	3.55E-04	2.34E+03	2.24E+03	4.645	
3	4.43E-04	1.70E+03	1.69E+03	0.394	
4	5.64E-04	1.24E+03	1.25E+03	-0.664	
5	7.13E-04	9.73E+02	9.40E+02	3.512	
6	8.81E-04	7.28E+02	7.28E+02	-0.018	
7	8.90E-04	6.71E+02	7.20E+02	-6.679	
8	1.10E-03	5.74E+02	5.64E+02	1.757	
9	1.10E-03	5.19E+02	5.62E+02	-7.563	
10	1.40E-03	4.01E+02	4.26E+02	-5.770	
11	1.41E-03	4.41E+02	4.22E+02	4.609	
12	1.77E-03	3.12E+02	3.27E+02	-4.602	
13	1.80E-03	3.44E+02	3.22E+02	6.632	
14	2.20E-03	2.55E+02	2.59E+02	-1.652	
15	2.80E-03	2.00E+02	2.00E+02	-0.298	
16	3.55E-03	1.53E+02	1.57E+02	-2.774	
17	4.43E-03	1.23E+02	1.27E+02	-2.962	
18	5.64E-03	1.01E+02	1.01E+02	0.174	
19	7.13E-03	8.14E+01	8.17E+01	-0.310	
20	8.81E-03	6.77E+01	6.79E+01	-0.186	
21	1.10E-02	5.59E+01	5.67E+01	-1.421	
22	1.41E-02	4.63E+01	4.66E+01	-0.754	
23	1.80E-02	3.85E+01	3.89E+01	-1.169	
24	2.22E-02	3.45E+01	3.36E+01	2.618	
25	2.85E-02	2.89E+01	2.84E+01	1.716	
26	3.60E-02	2.52E+01	2.44E+01	3.026	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 26 DATA POINTS, RAMP: 210.0 MICROSEC, DATA: J1

RMS LOG ERROR: 2.59E-02, ANTILOG YIELDS 6.1356 %
LATE TIME PARAMETERS

* Blackhawk Geosciences *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

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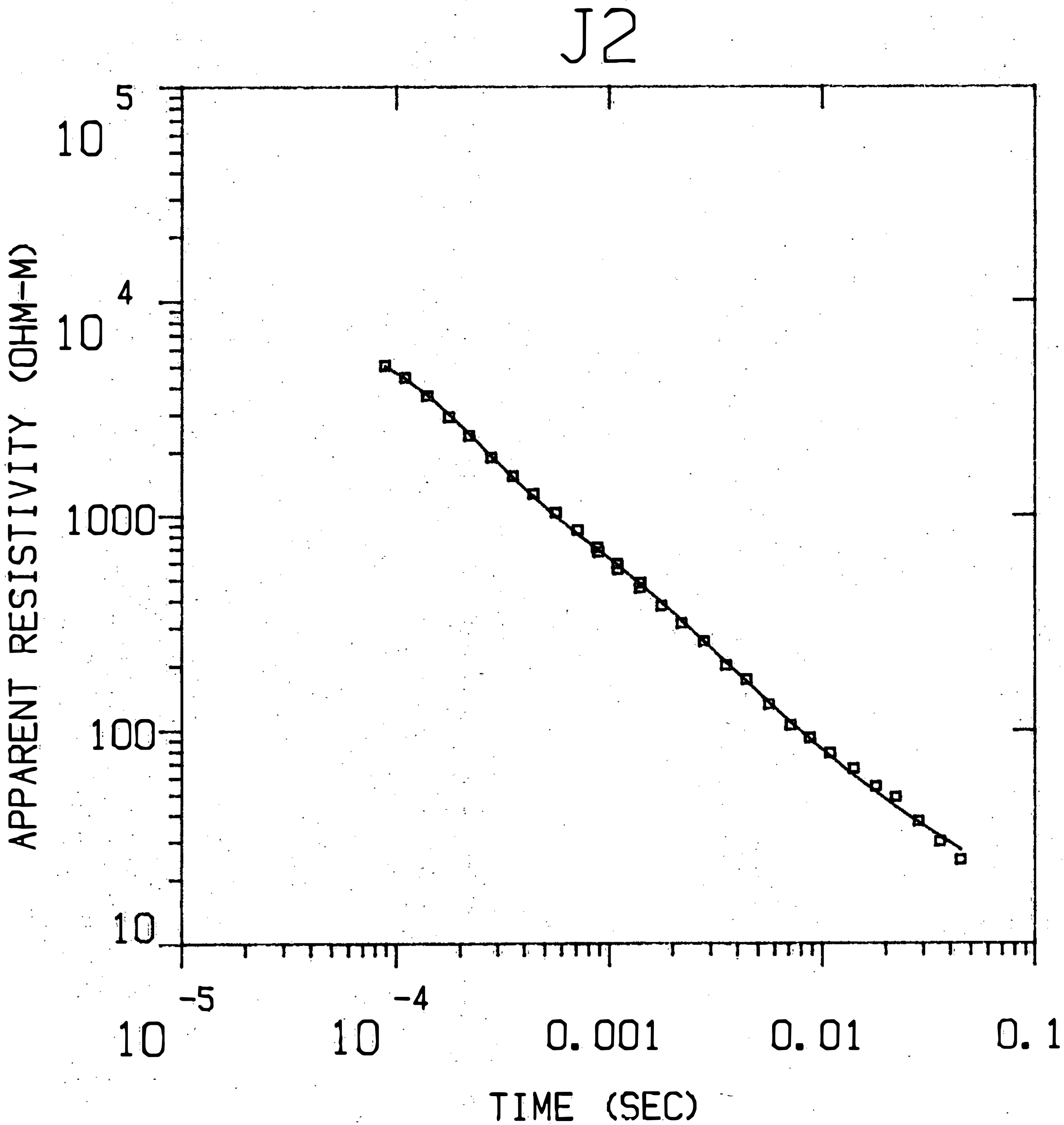
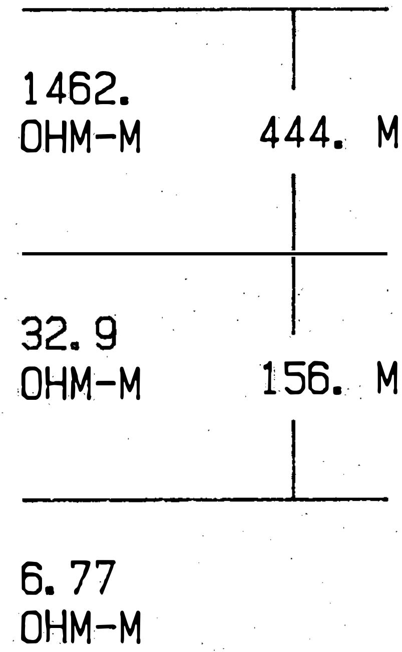
P 2	-0.03	0.96	
T 1	0.01	0.00	1.00
	P 1	P 2	T 1



MODEL:



% ERROR: 6.55
CALIBRATION: 1
OFFSET: 152. M
RAMP: 210.0
Blackhawk Geosciences

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		396.2	1300.0		
1462.05	443.9	-47.6	-156.3	0.3	0.3
32.94	156.5	-204.1	-669.7	4.8	5.1
6.77					

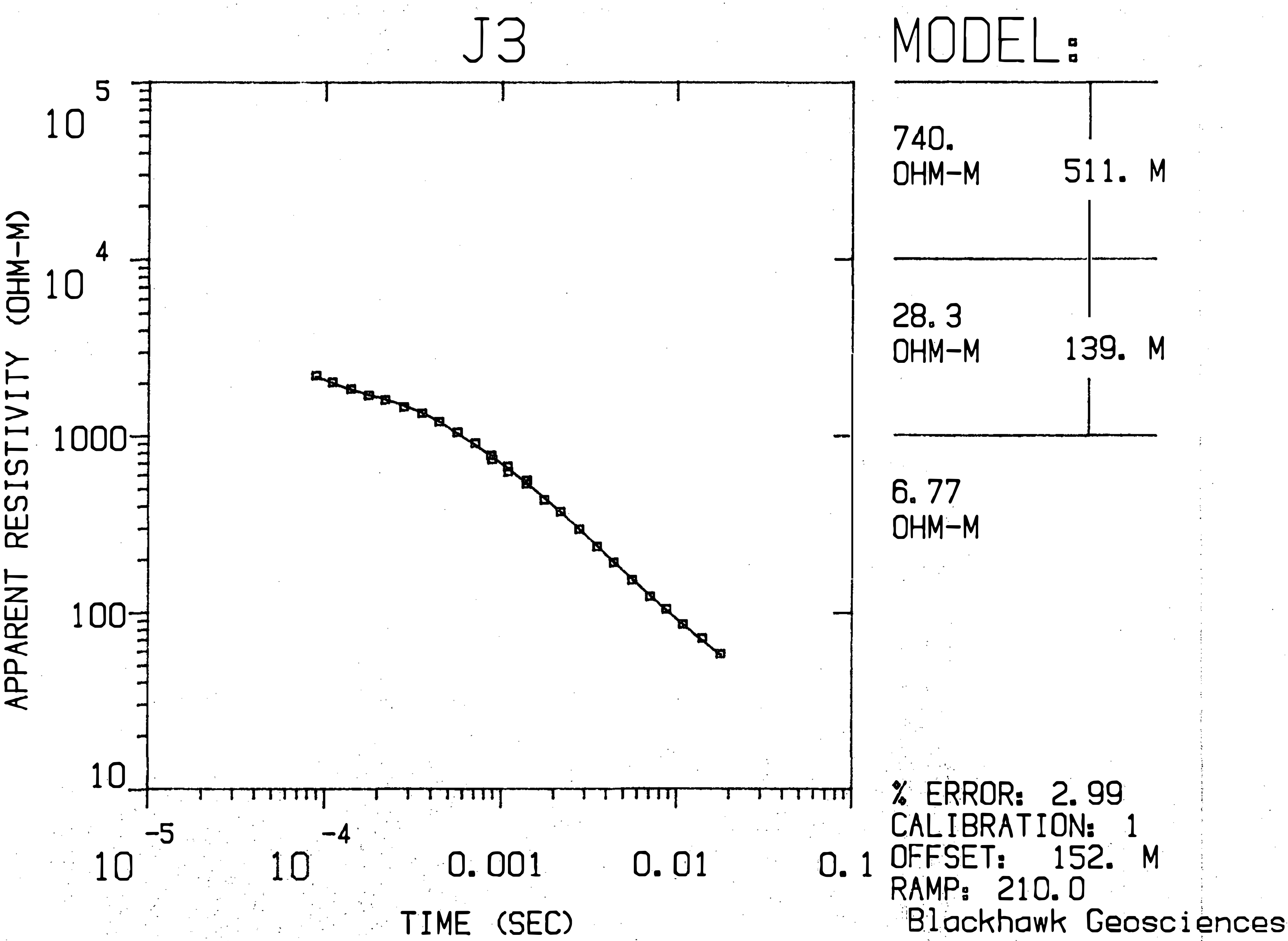
	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	5.05E+03	5.00E+03	0.999	
2	1.10E-04	4.44E+03	4.41E+03	0.607	
3	1.40E-04	3.65E+03	3.69E+03	-1.008	
4	1.77E-04	2.91E+03	3.00E+03	-2.922	
5	2.20E-04	2.38E+03	2.43E+03	-2.297	
6	2.80E-04	1.88E+03	1.91E+03	-1.304	
7	3.55E-04	1.54E+03	1.51E+03	1.898	
8	4.43E-04	1.27E+03	1.23E+03	2.983	
9	5.64E-04	1.03E+03	9.92E+02	4.023	
10	7.13E-04	8.54E+02	8.17E+02	4.497	
11	8.81E-04	7.06E+02	6.95E+02	1.574	
12	8.90E-04	6.73E+02	6.90E+02	-2.462	
13	1.10E-03	5.93E+02	5.84E+02	1.464	
14	1.10E-03	5.56E+02	5.82E+02	-4.481	
15	1.40E-03	4.57E+02	4.76E+02	-4.113	
16	1.41E-03	4.83E+02	4.73E+02	2.169	
17	1.77E-03	3.78E+02	3.93E+02	-3.881	
18	2.20E-03	3.13E+02	3.23E+02	-3.174	
19	2.80E-03	2.58E+02	2.59E+02	-0.283	
20	3.55E-03	2.01E+02	2.07E+02	-3.290	
21	4.43E-03	1.72E+02	1.69E+02	2.218	
22	5.64E-03	1.32E+02	1.35E+02	-2.466	
23	7.13E-03	1.06E+02	1.09E+02	-3.282	
24	8.81E-03	9.20E+01	9.08E+01	1.291	
25	1.10E-02	7.81E+01	7.56E+01	3.371	
26	1.41E-02	6.60E+01	6.14E+01	7.536	
27	1.80E-02	5.44E+01	5.11E+01	6.336	
28	2.22E-02	4.84E+01	4.36E+01	11.080	
29	2.85E-02	3.72E+01	3.67E+01	1.245	
30	3.60E-02	2.98E+01	3.15E+01	-5.586	
31	4.49E-02	2.45E+01	2.74E+01	-10.676	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 31 DATA POINTS, RAMP: 210.0 MICROSEC, DATA: J2
2501 004N 002N Z OPR XTL H 6 8+100
Ch.21 = 0.21 Ch.22 = 0.089 Ch.23 = 20.5 Ch.24 =
RMS LOG ERROR: 2.76E-02, ANTILOG YIELDS 6.5499 %
LATE TIME PARAMETERS

* Blackhawk Geosciences *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	1.00				
P 2	0.00	1.00			
F 3	0.00	0.00	0.00		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	0.00	0.00	1.00
	P 1	P 2	F 3	T 1	T 2



J3
MODEL:
740.
OHM-M
511. M
28.3
OHM-M
139. M
6.77
OHM-M
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
10^-5
10^-4
0.001
0.01
0.1
TIME (SEC)
% ERROR: 2.99
CALIBRATION: 1
OFFSET: 152. M
RAMP: 210.0
Blackhawk Geosciences

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		412.4	1353.0		
740.15	510.6	-98.2	-322.2	0.7	0.7
28.31	138.7	-236.9	-777.3	4.9	5.6
6.77					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	2.21E+03	2.19E+03	1.126	
2	1.10E-04	2.02E+03	2.00E+03	1.045	
3	1.40E-04	1.86E+03	1.84E+03	0.784	
4	1.77E-04	1.71E+03	1.72E+03	-0.690	
5	2.20E-04	1.60E+03	1.62E+03	-0.924	
6	2.80E-04	1.46E+03	1.49E+03	-2.288	
7	3.55E-04	1.34E+03	1.35E+03	-0.774	
8	4.43E-04	1.20E+03	1.21E+03	-0.271	
9	5.64E-04	1.05E+03	1.03E+03	1.587	
10	7.13E-04	9.06E+02	8.81E+02	2.861	
11	8.81E-04	7.72E+02	7.66E+02	0.797	
12	8.90E-04	7.33E+02	7.60E+02	-3.601	
13	1.10E-03	6.70E+02	6.52E+02	2.809	
14	1.10E-03	6.23E+02	6.50E+02	-4.160	
15	1.40E-03	5.34E+02	5.38E+02	-0.884	
16	1.41E-03	5.58E+02	5.35E+02	4.276	
17	1.77E-03	4.34E+02	4.47E+02	-2.779	
18	2.20E-03	3.72E+02	3.71E+02	0.404	
19	2.80E-03	2.96E+02	2.97E+02	-0.267	
20	3.55E-03	2.37E+02	2.39E+02	-0.991	
21	4.43E-03	1.92E+02	1.94E+02	-0.841	
22	5.64E-03	1.53E+02	1.55E+02	-1.271	
23	7.13E-03	1.24E+02	1.25E+02	-1.182	
24	8.81E-03	1.05E+02	1.03E+02	1.369	
25	1.10E-02	8.59E+01	8.59E+01	0.001	
26	1.41E-02	7.16E+01	6.94E+01	3.172	
27	1.80E-02	5.80E+01	5.74E+01	1.026	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 27 DATA POINTS, RAMP: 210.0 MICROSEC, DATA: J3
2501 004N 003N Z OPR XTL H 6 8+100
Ch.21 = 0.21 Ch.22 = 0.089 Ch.23 = 20.5 Ch.24 =
RMS LOG ERROR: 1.28E-02, ANTILOG YIELDS 2.9943 %
LATE TIME PARAMETERS

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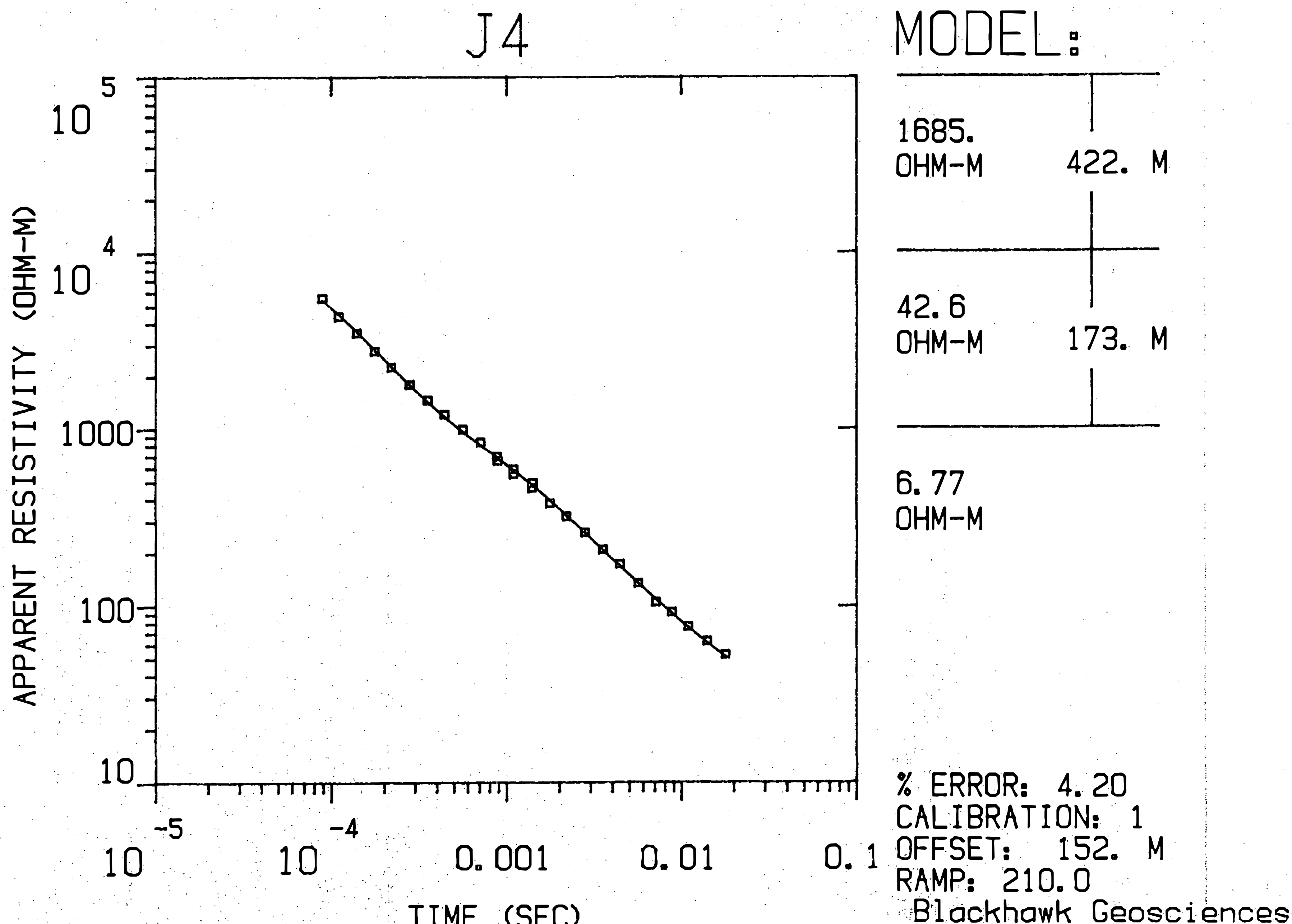
PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	1.00				
P 2	0.00	0.99			
F 3	0.00	0.00	0.00		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	0.00	0.00	1.00
	P 1	P 2	F 3	T 1	T 2


J4
MODEL:
1685.
OHM-M
422. M
42.6
OHM-M
173. M
6.77
OHM-M
% ERROR: 4.20
CALIBRATION: 1
OFFSET: 152. M
RAMP: 210.0
Blackhawk Geosciences
APPARENT RESISTIVITY (OHM-M)
10^5
10^4
1000
100
10
TIME (SEC)
10^{-5}
10^{-4}
0.001
0.01
0.1

MODEL: 3 LAYERS

RESISTIVITY (OHM-M)	THICKNESS (M)	ELEVATION (M)	ELEVATION (FEET)	CONDUCTANCE (S) LAYER	CONDUCTANCE (S) TOTAL
		390.8	1282.0		
1685.24	421.6	-30.9	-101.3	0.3	0.3
42.56	172.7	-203.6	-667.9	4.1	4.3
6.77					

	TIMES	DATA	CALC	% ERROR	STD ERR
1	8.90E-05	5.56E+03	5.39E+03	3.119	
2	1.10E-04	4.38E+03	4.53E+03	-3.306	
3	1.40E-04	3.53E+03	3.60E+03	-1.899	
4	1.77E-04	2.79E+03	2.84E+03	-1.892	
5	2.20E-04	2.25E+03	2.27E+03	-0.922	
6	2.80E-04	1.79E+03	1.77E+03	0.642	
7	3.55E-04	1.45E+03	1.42E+03	2.486	
8	4.43E-04	1.20E+03	1.17E+03	3.285	
9	5.64E-04	9.90E+02	9.56E+02	3.570	
10	7.13E-04	8.35E+02	8.05E+02	3.817	
11	8.81E-04	6.95E+02	6.90E+02	0.681	
12	8.90E-04	6.58E+02	6.85E+02	-4.030	
13	1.10E-03	5.91E+02	5.82E+02	1.467	
14	1.10E-03	5.52E+02	5.80E+02	-4.835	
15	1.40E-03	4.62E+02	4.82E+02	-4.213	
16	1.41E-03	4.94E+02	4.79E+02	3.096	
17	1.77E-03	3.80E+02	3.96E+02	-4.121	
18	2.20E-03	3.20E+02	3.25E+02	-1.356	
19	2.80E-03	2.60E+02	2.60E+02	-0.017	
20	3.55E-03	2.09E+02	2.08E+02	0.651	
21	4.43E-03	1.73E+02	1.69E+02	2.299	
22	5.64E-03	1.35E+02	1.35E+02	-0.425	
23	7.13E-03	1.05E+02	1.09E+02	-3.900	
24	8.81E-03	9.22E+01	9.08E+01	1.539	
25	1.10E-02	7.61E+01	7.53E+01	1.137	
26	1.41E-02	6.28E+01	6.14E+01	2.288	
27	1.80E-02	5.25E+01	5.10E+01	3.042	

R: 152. X: 0. Y: 152. DL: 305. REQ: 169. CF: 1.0000
CLHZ ARRAY, 27 DATA POINTS, RAMP: 210.0 MICROSEC, DATA: J4
2501 004N 004N Z OPR XTL H 6 8+100
Ch.21 = 0.21 Ch.22 = 0.089 Ch.23 = 20.5 Ch.24 =
RMS LOG ERROR: 1.79E-02, ANTILOG YIELDS 4.1977 %
LATE TIME PARAMETERS

* Blackhawk Geosciences *

PARAMETER RESOLUTION MATRIX:
"F" MEANS FIXED PARAMETER

P 1	1.00				
P 2	0.00	1.00			
F 3	0.00	0.00	0.00		
T 1	0.00	0.00	0.00	1.00	
T 2	0.00	0.00	0.00	0.00	1.00
	P 1	P 2	F 3	T 1	T 2